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A Changing Gulf of Maine: Investigating the Role of Benthic Water Temperature in Determining the Timing of Spiny Dogfish (Squalus acanthias) Arrival and Departure in the Gulf of Maine

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Title:
A Changing Gulf of Maine: Investigating the Role of Benthic Water Temperature in Determining the Timing of Spiny Dogfish (*Squalus acanthias*) Arrival and Departure in the Gulf of Maine

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Abstract:
Spiny Dogfish (*Squalus acanthias*) is a highly migratory elasmobranch that undergoes annual migrations along the East Coast of the United States. Spiny dogfish have been studied extensively on the West Coast, but little information currently exists on the life history of this species in the Gulf of Maine (GOM). In the last few years, commercial gillnet fishermen in the GOM have been reporting unusual catch patterns while fishing offshore, perhaps indicating an increased abundance in dogfish and an extension of the length of time that dogfish occupy the GOM in a given year. Concurrent with these changes, rising average global temperatures have led to increased ocean temperatures in the GOM, a variable that could be altering the historical movement patterns of GOM fish. These changes are likely to have important ecological impacts and implications for commercial fisheries. This project sought to investigate the relationship between benthic water temperature and the presence or absence of spiny dogfish off the coast of New Hampshire. A greater understanding of the relationship between benthic water temperature and dogfish presence could increase the efficiency of commercial gillnet fishermen targeting spiny dogfish (e.g. targeting specific areas of a certain water temperature), increase our capacity to successfully manage the dogfish fishery, and suggest ecological impacts for these changes. Utilizing vessels in the NH Gillnet fishing fleet, dogfish catch and benthic water temperature were tracked seasonally from 2014-2016 over the course of three separate phases (Phase I – 2014, Phase II – 2015, Phase IIIA/IIIB – 2016). Limited data was also collected by recreational fishermen during 2016. Results indicated a threshold of approximately 5.0˚C benthic water temperature before dogfish arrival in 2014 in late June. In 2015 and 2016, dogfish time of departure was calculated on 8/17/2015 and 8/08/2016 when benthic water temperature was 6.16˚C and 7.42˚C respectively. The similarity in date but difference in water temperature indicate potentially a potential photoperiod correlation associated with the timing of dogfish departure. Initial observations were also made concerning patterns of sex ratio associated with spiny dogfish at Jeffrey's Ledge,

perhaps indicating separate movement patterns associated with differences in age/sex. Additional data is needed to improve the foundational work presented in this pilot study.

Introduction:

The Gulf of Maine (GOM) is a coastal ecosystem extending from Nantucket Shoals and Cape Cod to the Southern shores of New Brunswick and Nova Scotia (Bigelow and Schroeder 1953). Seasonal phytoplankton blooms, most notably during early spring (March-April; Bigelow (1926) make this large gulf a productive ecosystem by providing the primary energy source for a wide diversity of life. The area has traditionally been a popular fishing area for commercial and recreational fishermen searching for groundfish species along the continental shelf (Ames 2004). The origin and growth of coastal communities founded by European colonists along the GOM was linked to success of commercial fishing. Commercial fishing continues to be an important economic activity for GOM states. In 2015, records indicate the harvesting of 291,513 metric tons of finfish in the GOM, equating to $1.19 million USD (Fisheries of the United States – NOAA 2015).

The early history of fishing in the GOM was characterized by an explosion of techniques and technologies utilized to increase catch-per-unit-effort (CPUE) for fishermen. Traditional hook-and-line fishing was replaced by beam trawling in the 18th century. During the Industrial Revolution, the invention of diesel-powered vessels allowed fishermen to travel faster and farther offshore, thus increasing the time and area for fishing (Jackson *et al.* 2001). Lack of strong management structures and scientific knowledge allowed unsustainable practices to continue into the 20th century before regulations came in to effect. By this time historically important groundfish stocks, including atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and atlantic pollock (*Pollachius pollachius*) had become severely depleted. This trend has since continued into the 21st century. Since the late 20th century, most historically important commercial groundfish landings have been strictly monitored with almost annual decreases in the Total Allowable Catch (TAC). For example, in one New Hampshire port, from 2005-2015 the annual landings of Atlantic Cod dropped at Hampton Harbor (Hampton, NH) from over 560,000 pounds (2005) to approximately 25,000 pounds (2015), a decrease of over 2000% [Standard Atlantic Fisheries Information Service (SAFIS) - Yankee Fishermen's Cooperative]. The continued decreases in catch have forced commercial fishermen to shift from fishing of traditional species to non-traditional species, such as the spiny dogfish (*Squalus acanthias*).

The fishery for spiny dogfish has existed since the 1870s with harvesting used to produce oils for use in household lamps (McFarland & Beamish 1987). Since declines of groundfish stocks began in the mid 20th century, spiny dogfish biomass has increased substantially (Rago *et al.* 1998). In 2015, commercial landings along the Atlantic Coast of the United States indicate spiny dogfish as the most harvested commercial finfish (20.7 million pounds) and the second highest overall (commercial and recreational landings) falling only behind Striped Bass (*Morone saxatilis*) (Fisheries of the United States, NOAA 2015). In particular to the coast of New Hampshire, spiny dogfish catch has dramatically increased from 2005 (65,780 pounds) to 2015 (819,270 pounds; SAFIS Yankee Fishermen's Cooperative).

Unlike traditional groundfish species, the spiny dogfish is as a highly migratory species (HMS) with annual movements from Cape Hatteras to the Gulf of Maine during early spring and subsequent returns during the fall (NOAA fisheries – Greater Atlantic Region). Despite this expected phenomenon, critical natural history characteristics of spiny dogfish remain unknown. Notable characteristics still poorly understood include maximum age (estimates up to 35-40 years old (Nammack *et al.* 1982)), age at reproduction (estimates ranging from 6-12 years (Bubbley *et al.* (2011 + 2013) and locations/times for pupping (Sulikowski *et al.* 2013). In addition, the mechanism behind their annual migrations is not well understood, as the physical or ecological drivers leading them to migrate has not been studied. Recent reports have even indicated the existence of two separate stocks of spiny dogfish along the Northeast Shelf Large Marine Ecosystem (NESLME; Carlson *et al* 2014). Overall, significant gaps in knowledge exist in the life history of spiny dogfish in the Gulf of Maine limiting our capacity to successfully manage the fishery as it experiences increasing fishing pressure.

Understanding the seasonal migration patterns of economically important groundfish has become an area of great scientific inquiry (Leggett 1977) especially concerning the success of commercial fishermen. Much of what has been recently discovered in fish migration patterns has been learned using satellite telemetry and acoustic fish tag methods (Akesson 2002). Water temperature has been suggested as a primary explanation for patterns in fish availability by fishermen (Chapman *unpublished*). Scientific evidence for this relationship has been found throughout aquatic communities and across trophic levels in the ecosystem. Examples of this include the effect of temperature driving spawning patters of river salmonid species (Trépanier *et al.* 1995) and the observations of seasonal changes in *Alexandrium fundyense*, a diatom found in the Gulf of Maine (McGillicuddy *et al.* 2005). Fishermen have been reporting unusual patterns in fish availability in the past few years, possibly an effect of rising ocean temperatures being found worldwide (Rose, 2005; Perry *et al.* 2005). Evidence also supports the pole ward movement of known dogfish prey including American Shad (6.86 km yr^{-1}) and Silver hake (3.58 km yr^{-1}) from warming ocean temperatures (Nye *et al.* 2009).

Given that spiny dogfish is an emerging fishery in the GOM and recent evidence of changing water temperatures effecting on fish movements, this study sought to examine this relationship at prominent fishing grounds off the coast of New Hampshire. From 2014 – 2016, seasonal (June – October) benthic water temperatures were monitored onboard commercial New Hampshire gillnet vessels and a New Hampshire charter fisherman along Jeffrey's Ledge by a New Hampshire Sea Grant research technician. Jeffrey's Ledge is located approximately 29 miles off the coast of New Hampshire and is a popular fishing ground with historically high densities of groundfish (Witman & Sebens 1992). Benthic water temperature at Jeffrey's Ledge were linked with the daily catch of spiny dogfish collected by the fishermen. This linkage of dogfish catch with real time benthic water temperature sought to determine a pattern for when spiny dogfish arrive to Jeffrey's Ledge in the spring (e.g. migrating up from their overwintering grounds) and a temperature at which they potentially exit to return south in the fall. Having data collected from 2014-2016, potential differences in temperature with subsequent changes in dogfish catch could indicate the abundance of spiny dogfish in a given area. In addition to real time data collected from 2014-2016, historical data of dogfish catch was compiled dating back to

2005 to potentially determine when influx of dogfish catch began and how long it lasted into the summer and/or fall.

Measuring spiny dogfish catch during the late spring, summer, and early fall period provides critical insight into their movement patterns in the GOM. In particular, the determination of their time of arrival and time of departure at Jeffrey's Ledge is essential to proper management of the fishery in New Hampshire waters and may also provide insight into their movements before entering Jeffrey's Ledge and movements once they leave in the fall. It is proposed that these critical time points are strongly correlated to benthic water temperature, a variable that fishermen have historically monitored when targeting groundfish.

Hypothesis:

It is hypothesized that spiny dogfish time of arrival (TOA) and time of departure (TOD) are correlated with benthic water temperature (˚C) at Jeffrey's Ledge. TOA will be correlated with water temperatures increasing above a critical point and TOD will be correlated with a water temperature decreasing below the same/different critical temperature.

Methods:

Data during this study were collected at Jeffrey's Ledge (Figure 1). Benthic water temperature data was collected from 2014-2016 (Phases I-III) from approximately June 3 – October 31. Dogfish catch was collected using catch records from commercial fishermen, the Yankee Fishermen's Cooperative (Seabrook, NH) via the Standard Atlantic Fisheries Information System (SAFIS), or by a technician aboard fishing vessels. Arrival and time of departure of historical spiny dogfish landings was assessed visually using time-series plots of catch data (Figures 2 and 3).

Phase I - 2014:

Analysis of data in 2014 focused on the Time Of Arrival (TOA) of spiny dogfish at Jeffrey's Ledge. Temperature data was collected from one commercial fisherman from 3 June 2014 to 16 June 2014. Corresponding catch data was provided from estimates from the commercial fisherman recorded in his daily logbook. Three experimental gillnet strings were evenly dispersed oriented North-to-South at three separate depths (Gillnet 1 – 30 fathoms, Gillnet 2 – 55 fathoms, Gillnet 3 – 65 fathoms). Gillnet strings were composed of 10-15 individual gillnets with 6.5" to 7" mesh. Average soak time for gillnet strings was 24 hours.

The temperature loggers (Visible Assets Inc. Stratham, NH) were deployed 1.5 m above the lead (bottom) line located at each corner of the respective gillnets (Figure 5). The tags recorded temperature every 7.2 minutes at 0.5˚C resolution. Tag data was analyzed to provide mean bottom temperature (˚C) per string in addition to temperature (˚C) interpolated across the experimental gillnets using MATLAB (MathWorks®). Temperature results were transmitted wirelessly to a receiver box located in the wheelhouse of the ship. This data was subsequently downloaded from the boat at the end of Phase I.

The catch data and temperature data were extrapolated using an XYY scatterplot on Microsoft® Excel® for Mac 2011 (14.7.0). Regression analysis was conducted to determine patterns of temperature change and dogfish catch during the study period. Some dates have multiple temperature and dogfish catch data points to delineate differences between the three experimental gillnets.

Phase II - 2015:

Data collection from 2015 focused on the Time Of Departure (TOD) of spiny dogfish at Jeffrey's Ledge. Data was collected from one commercial fisherman from 8 August 2015 to 3 September 2015. Corresponding catch data was provided from 9 August 2015 – 25 September 2015. These estimates came from the commercial fisherman, recorded in his daily logbook. Catch data also included landings collected from gillnet strings without temperature loggers attached. It was assumed for the purposes of this project that the relative locations of the gillnet string was negligible as the strings were located very close to one another. Catch data was therefore clumped to include non-tagged gillnets to prevent the fishermen tediously counting out fish from the experimental nets.

Catch data was not recorded on 8 August due to refurbishing of the data loggers. Temperature data was also not recorded on 24 August due to removal of the temperature loggers prior to the fisherman's last day of fishing. All attributes of the temperature loggers and data analysis were identical to Phase I (see above) except the temperature loggers collected recordings once per hour (23 recordings * day^{-1}) and were averaged to provide one mean temperature value for each day (±SE).

In addition to data analysis as conducted in Phase I, linear and polynomial regression was conducted on the collected temperature and dogfish catch respectively. A polynomial regression was run on dogfish catch as it was assumed that dogfish would eventually leave the Jeffrey's Ledge research area, thus signifying a steady decrease in catch resembling a parabolic function. The maximum value of the parabolic function was computed by determining the maximum y-value of the function over the range of x-values (dates) of the experiment. This maximum value thus provided a statistical estimate of dogfish departure from the research site. This value could then be compared to the value calculated using the same methods during Phase III to determine if the TOD differed from 2015 to 2016.

Also, variance ($Log_{10}(variance^2)$) of dogfish catch was computed by analyzing differences in daily catch of dogfish versus the average throughout the research period (8 August – 25 September). Analysis of dogfish variance thus acted as a means to quantify spatial dispersion of dogfish in the Jeffrey's Ledge research area. It is assumed that as dogfish depart the fishing area, catch rates will become more variable as one large, dense grouping of fish transitions into many smaller groups of fish occupying the area. Thus, when the variance of dogfish catch increases, it can be used as an additional method for identifying the timing of dogfish departure from the area. Changes in dogfish variance from the mean value were calculated using the test of significance involving the sample average (Figure 5).

Phase IIIA – 2016:

Commercial Fishermen

Two commercial fishermen participated in Phase III of this project spanning 29 June 2016 to 31 October 2016. The temperature loggers for Phase III included three tidbit v2 temperature loggers (Figure 6; Onset ® HOBOware data loggers, Bourne, MA) given to each fisherman. The temperature loggers were changed between Phases II – III in order to increase the time resolution of water temperature collection (once every 7.2 minutes – once every minute). In addition the tidbit v2 loggers were smaller and did not require a receiving box in the wheelhouse of the ship. Temperature loggers were attached with a small piece of string to the monofilament directly above the lead line of three separate gillnets (e.g. three tagged gillnets per fishermen, therefore 6 tagged gillnets for the study). The tidbit v2 loggers were programmed to record temperature continuously once per minute for approximately 31 days. Temperature data was transferred wirelessly to a U-DTW-1 HOBOware Waterproof Shuttle once per week. Transfer was conducted by manually attaching the transfer shuttle to each respective temperature logger once per week during daily fishing trips by the commercial fishermen. Transferring of data deleted existing data on the logger to prevent reaching storage capacity during the field season.

The commercial fishermen fished in two separate locations. Fisherman 1 fished primarily at Jeffrey's Ledge. Fisherman #1 fished consistently from 30 June 2016 to 23 September 2016 with an additional 3 fishing days from 5 October 2016 to 8 October 2016. Catch data was provided from fisherman #1's landings via SAFIS through the Yankee Fisherman's Cooperative (Seabrook, NH). Temperature loggers were deployed on gillnet strings of either 6.5", 7", or 12" mesh. The average soak time for the gillnets was 1-2 days from late June to the beginning of August and during the short fishing time in October. Average soak time increased to 2-4 days from late August through late September. Data analysis of dogfish catch and temperature data followed the same procedure as outlined during Phase II (see above) except calculation of standard error (SE) for benthic water temperature only involved differences between the three Tidbit v2 temperature loggers across the different gillnet strings. SE of temperature was not calculated to account for error associated between each minute of each day as recorded by the temperature loggers.

Fisherman 2 (hereafter known as #2) primarily fished at Platt's Bank, a popular fishing area located approximately 60 miles off the coast of New Hampshire. Fisherman #2 fished for monkfish (*Lophius spp.*) instead of dogfish, therefore only temperature data was collected from gillnets utilized by #2. Mesh size for gillnets was 11" – 12" and average soak time was 3-5 days. Temperature data was collected approximately once every two weeks using the same method as described with #1. Calculation of water temperature SE was also calculated in a similar manner as to #1.

The inclusion of #2 outside of the typical Jeffrey's Ledge research area sought to expand the scope of this project to potentially connect benthic water temperature data from both sites. Therefore if connections could be made between separate sites, there was the potential to expand these patterns to additional areas in the Gulf of Maine.

Phase IIIB – 2016:
Recreational Fishermen

A charter fisherman from Seabrook, NH was recruited to provide hook and line dogfish catch in addition to benthic water temperature data. Research trips were conducted weekly at Jeffrey's Ledge during the charter fisherman's daily activity taking clients out deep sea fishing. The fisherman and his clients targeted gadoid groundfish (Atlantic Cod, Haddock) but often caught spiny dogfish as bycatch.

Standard deep sea groundfish gear was utilized by the clients on board the charter vessel. This included Penn ® baitcaster reels (Spirit Lake, PA) with rods ranging from 1.5-1.75 m. The fishing rods were equipped with 30 lb. test monofilament fishing line fixed with two 2/0 size baitholder hooks and a 14-16 oz lead sinker approximately 20 cm from the hooks further down the fishing line (Deep Drop Rig – Ellis 2014). The rigs were baited with fresh clam and subsequently dropped to the sea floor. The dogfish bycatch was counted manually by the field technician.

During the course of the research trips, the captain moved around within a small area in order to provide ample opportunity for the clientele to catch fish. At each one of these locations benthic water temperature was recorded using a Sontek Castway CTD (San Diego, CA). The CTD was incased in a soft rubber sheath that was manually attached to a specially rigged deep sea fishing pole utilized by the field technician. The rod was fitted with braided line and a small piece of rope firmly lashing the CTD to the fishing rod. A 16 oz lead sinker was attached to the bottom of the CTD via an additional piece of Rope**.** At each fishing location, the CTD was vertically dropped in the water column to the sea floor. As soon as the lead sinker hit the bottom the CTD was subsequently reeled up. The data for each cast was electronically stored on the CTD and offloaded onto the Castaway CTD Software & Offline Map Add on (V 1.5 JAN2012). Average thermal stratification graphs are provided for 2 fishing days (29 June 2016 and 4 August 2016) in addition to XYY plots of dogfish catch vs. average benthic water temperature throughout the course of the fishing season (late June – Early September). The average benthic water temperature was calculated by averaged the bottom 1 m of water temperature from the CTD across all locations from each respective day. Because the waters being fished by the charter fisherman were similar to those fished by #1, a two-tailed t-test was conducted to determine if there was a significant difference in recorded benthic water temperatures by the Tidbit v2 temperature loggers (used by the commercial fisherman) and the Sontek Castaway CTD (used on trips with the charter fisherman). This test was conducted on Social Science Statistics (socscistatistics.com) ©2017 Jeremy Stangroom.

Similar to analysis of catch data from #1 in Phase IIIA, dogfish catch was fit to a polynomial function using Microsoft Excel® for Mac 2011 (14.7.0) in order to determine the TOD and the benthic water temperature collected closest to this date. This result was then compared to the TOD collected during Phase IIIA. It is unknown at this time how to directly compare effort and catch amounts of spiny dogfish between hook-and-line and standard gillnet equipment. Nonetheless similar results for TOD and benthic water temperature at TOD would support the ability to use recreational landings of spiny dogfish to determine TOD.

Temperature Comparison: Phase II + IIIA

Phases II and IIIA of this project (2015 and 2016 commercial) overlapped from 8 August to 3 September (e.g. end of summer). Comparison of the benthic water temperature was plotted from this time period to indicate 1.) Differences between benthic water temperature at Jeffrey's Ledge from 2015-2016 and 2.) Distinguish potential temperature differences between Jeffrey's Ledge and Platt's Bank. Difference in temperature associated with changes in dogfish catch could therefore indicate an ecological response of the sharks to benthic water temperature. Indication of more dogfish at higher temperatures would support the my hypothesis whereas lower temperatures supporting high dogfish populations would indicate the influence of other variables.

All three temperature series were plotted in their entirety using Microsoft® Excel® for Mac 2011 (14.7.0). The samples from 8 August to 3 September were analyzed to test for significant difference between the three groups (temperature 2015 Jeffrey's Ledge, temperature 2016 Jeffrey's Ledge, temperature 2016 Platt's Bank) using a One-way ANOVA and Tukey HSD Test on VassarStats: Website for Statistical Computation ©Richard Lowry.

Results:

Phase I – 2014:

Spiny dogfish were caught sparingly during the early summer data collection of Phase I. Dogfish were absent entirely from early research days 6/03 – 6/07 and were not caught until 6/14. The maximum spiny dogfish catch was recorded on 6/16 with 2,000 U.S. lbs. caught in Gillnet 3 at 65 fathoms. Dogfish catch during Phase I indicated a 2nd order polynomial function regression model ($10.217x^2 - 77.263x + 109.97$, $R^2 = 0.678$, Figure 7).

Benthic water temperature increased linearly at a rate $y = 0.0598x + 4.1785$ (Adj. $R^2 = 0.436$, Figure 7) across all three gillnets. Temperature was recorded at its lowest on 6/07 at 3.99˚C (Gillnet 2) while water temperature increased up to 5.50˚C on 6/16 (Gillnet 1). Individually across the three gillnets, water temperature increased from 4.67˚C – 5.50˚C (Gillnet 1), 3.99˚C – 5.16˚C (Gillnet 2), and 4.13˚C – 4.68˚C (Gillnet 3). Spiny dogfish did not appear in the research area until 6/14 when water temperatures at the sea-bed near the gillnets was below 4.6˚C. The maximum dogfish catch (2,000lbs) was recorded at a water temperature of 4.68˚C.

Data collected from temperature interpolation indicated water temperatures warming much faster at the shallower water gillnet (Gillnet 1 – 30 fathoms) compared to Gillnets 2 and 3 located in deeper waters (Figure 8). Water temperature was recorded warmer on the left sides of the gillnet strings at 55 and 60 fathoms (Gillnets 2 and 3) on June 3rd. The gillnet strings exhibited a similar pattern on 6/16 albeit water temperatures were markedly warmer. Gillnet string 1 indicated a uniform temperature throughout the individual gillnets.

Note for both series, x = the date where x = 1 = 6/03/2014 (e.g. x = 2 = 6/04/2014 etc.).

Phase II – 2015:

When collection of data began during early August, spiny dogfish were being caught consistently at the legal trip limit (5,000 U.S. lbs. * day^{-1}, Figure 9). This trend continued until the end of August when spiny dogfish catch decreased to approximately 20% the legal limit. This trend continued until the last few days of data collection when trip catch amounts continued to increase again up to the legal limit on 9/25 (Figure 9). The overall trend of decrease followed by a steep increase modeled a 3rd order polynomial function ($y = 0.3381x^3 - 25.172x^2 + 416.29x + 3141$, $R^2 = 0.57916$). Using the maximum value of the polynomial function across the range of x-values, it was determined that the TOD of spiny dogfish was 8/17. Beginning in mid-August, spiny dogfish catch began to increase following the calculate time of departure (8/17). Fitting a polynomial function estimates that spiny dogfish re-entered the fishing area around 9/15.

Benthic water temperature decreased during Phase II with a weak linear regression model ($y = -0.0019x + 6.1852$, $R^2 = 0.00185$, Figure 9). Temperature was recorded markedly lower from 8/21 – 8/25, greatly affecting the regression model for benthic water temperature. Benthic water temperature was recorded at a minimum 5.6˚C (8/22) and temperatures were recorded as high as 6.8˚C (8/12). The benthic water temperature on the approximated TOD was 6.16˚C (8/17). No benthic water temperature was available for the spiny dogfish during the time of reentry in mid-September (9/15) as the temperature loggers had been removed from the gillnets. The final day of temperature recording (9/03) yielded a reading of 6.5˚C.

During Phase II, variance in dogfish catch was recorded as a means to quantify spiny dogfish dispersion in addition to the polynomial regression computed from the catch data. As was previously computed, the TOD for spiny dogfish at Jeffrey's Ledge was 8/17 given the polynomial function best fit to the catch data. The average log variance in spiny dogfish catch was calculated at approximately 6.31 (Figure 10). Prior to the TOD, the spiny dogfish log variance was seen around 6.3-6.4 with an outlier on 8/17 with a value of 5.3. After the calculated TOD, the variance remained around 6.3-6.4 until the beginning of September when the variance increased to 6.8-6.9. These increases in variance indicated a higher rate of dispersion of spiny dogfish at Jeffrey's Ledge.

Phase IIIA – 2016

Commercial Fishermen (#1 and #2):

The two commercial fishermen during Phase IIIA were on the water consistently from the end of June until the beginning of October (#1) or the middle of November (#2).

At Jeffrey's Ledge, the benthic water temperature at the research area increased from a minimum of approximately 5.75˚C (late June) to 10.57˚C (early October). This increase in temperature favored a linear regression model 0.0351x + 5.7126 (R^2 = 0.8457; Figure 11). Note for this equation x = date where x = 1-101 (e.g. x = 1 = 6/30, x = 101 = 10/08).

Catch data collected from #1 revealed consistent commercial trip landings (5,000lbs/fishing day) until mid-August (Figure 11). This is also quantified in the average squared log variance that indicated little to no significant difference in spiny dogfish variance during this time period (Figure 12). From mid-August through the beginning of October, spiny dogfish catch became very random as catch limits ranged from 540 lbs. up to the daily limit of 5,000 lbs. The regression of the entire research fishing season indicated a 2nd order polynomial function $-0.9812x^2 + 79.191x + 3147.7$ (R^2 = 0.48029) from 6/30 to 10/08. The range of x-values for benthic water temperature mirrors that as used in the benthic water temperature linear regression (1-101, where x = 1 = 6/30/2016, and x = 101 = 10/08). Using the maximum value of the polynomial function across the range of x-values, it was determined that the spiny dogfish TOD at Jeffery's Ledge in 2016 was 8/08/2016. The temperature on this data was determined to be approximately 7.42˚C.

Despite the regression favoring a negative polynomial function and data suggesting spiny dogfish began exiting after 8/08, data collected on 9/04, 9/07, 9/09, 9/13, and 9/21 indicated 5000+lbs spiny dogfish/fishing day. This 'randomness' in spiny dogfish landings is emphasized in (Figure 12) supporting significant differences in spiny dogfish variance from 8/20 – 10/08.

Data collection from #2 involved only benthic water temperature collected at Platt's Bank. Benthic water temperature increased according to the linear regression model 0.0273x + 5.4083 (R^2 = 0.89927, Figure 13) where the range of x = (1:145) and x = 1 =

6/23, x = 145 = 11/15. The minimum water temperature recorded was 5.81˚C (late June) and the maximum water temperature recorded was 10.12˚C (mid November).

Phase IIIB – 2016
Charter Fisherman:

Weekly trips were taken with a New Hampshire charter fisherman on one of his boats. Benthic water temperature readings collected ranged from 6.00˚C ± 0.04 ˚C (7/08) – 8.31˚C ± 0.07˚C (8/27, Figure 14). Standard error for temperature is provided to account for slight temperature anomalies that were collected when the fisherman made small-scale moves at along Jeffrey's Ledge. Water temperatures rose progressively from the end of June to the end of August before a slight decrease was noted at the beginning of September. The increase in water temperature followed the linear regression $0.0307x + 6.1466$ (R^2 = 0.68147) where the range of x = (1:67) and x = 1 = 6/29, x = 67 = 9/03). A two-tailed t-test indicated no significant difference (p value = 0.43, t-value = -0.79) between benthic water temperatures collected onboard the charter fisherman's boat and temperature readings collected by #1 (Phase IIIA) also fishing Jeffrey's Ledge from 6/29 – 9/03.

Spiny dogfish catch by the charter fisherman and his clients was variable across the span of the 2016 fishing season. The maximum catch was estimated at 160lbs on 7/08 and the lowest catch was 0lbs on 6/29 and 8/18. Because the fishing methods between the commercial and charter fishermen differed (gillnets vs. hook and line, respectively) it was not possible to distinguish patterns between catch per unit effort between the commercial and recreational landings for spiny dogfish. The dogfish catch ranged from 0lbs (6/29/16) to 160lbs (7/09/16; Figure 14). Spiny dogfish landings began to increase following no dogfish catch on 8/18/16 up to 115lbs on 9/03/16, the last day of field data collection onboard the charter fisherman's vessel.

In relation to TOD, the recreational catch of spiny dogfish was fit to a 3rd order polynomial function $0.0073x^3 – 0.7254x^2 + 18.068x + 4.2108$ (R^2 = 0.69167) where the range of x = (1:67) and x = 1 = 6/29, x = 67 = 9/03). The TOD for this function was calculated at x = 16.62, equating to the date 07/16. No benthic water temperature values were recorded on this date. The closest date with benthic water temperature collection was 7/08 when water temperature was recorded at 6.00˚C ± 0.04 ˚C.

Because dogfish catch once again began to increase in late August, a time of reentry was calculated using the aforementioned polynomial function. This time of reentry was calculated on 8/17. The closest benthic water temperature record was collected 8/18 when the water temperature was calculated at 8.35˚C ± 0.07˚C.

Temperature Comparison - Phases II & IIIA:

The benthic water temperature data from Phase II and Phase IIIA were combined in *Figure 15*. The data values collected during Phases II and III indicate benthic water temperatures were warmer at Jeffrey's Ledge 2016 (Phase IIIA) compared to Jeffrey's Ledge 2015 (Phase II). Looking within the time period 8/08 – 9/23 in 2015 revealed an average temperature of 6.16˚C ± 0.07˚C (Figures 9 + 15). Benthic temperatures were seen warmer in 2016 over the same time span with an average of 7.73˚C ± 0.04˚C (Figures 11 + 15). Platt's Bank benthic water temperatures averaged at an intermediate 6.67˚C ± 0.02˚C over the same aforementioned time span in 2016. One-way analysis of variance (ANOVA) and Tukey's honest significant difference (HSD) test indicated a significant difference between the three temperature data sets ($P<0.0001$, Platts vs. Jeffrey's 2015 $P<0.01$, Platts vs. Jeffrey's 2016 $P<0.01$, Jeffrey's 2015 vs. Jeffrey's 2016 $P<0.01$; Table 1).

Discussion:

From 2014- 2016, spiny dogfish presence and abundance was monitored in relation to benthic water temperature at Jeffrey's Ledge, a popular fishing ground in the Gulf of Maine. Recent reports from fishermen have indicated unusual catch patterns for spiny dogfish in the last few years, inciting the desire to further understand their movement patterns. Results from the pilot testing from 2014-2016 focused on the time of arrival (TOA; 2014) and the time of departure (TOD; 2015-2016) at Jeffrey's Ledge off the coast of New Hampshire.

Data collection from Phase I does suggest that warming temperatures may be related to the arrival of dogfish in 2014, but the lack of data in 2015 and 2016 from this time period (mid-June) prevents any comparisons from being made during those years. It is important to note that fisherman activity is typically low during early June (Figures 2 + 3). This in turn led to the inability to collect data during the subsequent years (2015 + 2016). This project seeks to continue data collection in 2017 and beyond with heightened focus on TOA to allow for comparisons between the 2014 pilot TOA data collection.

Results from Phases II and IIIA (Jeffrey's Ledge) in 2015 and 2016 revealed similar patterns in dogfish catch despite significantly different benthic water temperatures. Compared to 2015, benthic water temperatures were notably higher in 2016 ranging from 5.7˚C (late June) – 10.6˚C (early October). This rate of increase far exceeded the rate of temperature change in 2015 where temperatures supported a decreasing rate of temperature change.

Data collection during 2016 strongly supported the use of dogfish catch variance as a means to quantitate dogfish time of departure. This relationship was not noted during 2015 albeit variance did slightly changed following the calculated TOD. More data that enables use of catch variance to indicate movement out of the area is needed to asses the utility of this working model. Utilizing dogfish variance has the potential of helping managers understand the moving aggregations of this emerging fishery at Jeffrey's Ledge and in the GOM as a whole. Future work associated with this study will also quantitate dogfish variance with their TOA during late spring/early summer.

Comparing dogfish catch and benthic water temperature data from 2015-2016 it becomes apparent that the dogfish began to leave earlier in 2016 despite the water temperatures being warmer compared to 2015. Looking at the water temperature at TOD, water temperatures were over 1˚C cooler in 2015 when the dogfish were determined to begin leaving. The large disparity in water temperature at TOD thus prevents the determination of a "critical" benthic water temperature at which dogfish leave the commercial fishing waters at Jeffrey's Ledge. These results instead suggest a different mechanism determining dogfish TOD. In both years dogfish left the research area at Jeffrey's Ledge within 10 days (8/17/2015 and 8/08/2016 respectively). This could potentially indicate spiny dogfish utilizing photoperiod or an innate annual rhythm that dictates their movements into and out of the Jeffrey's ledge fishing area.

An additional difference between landings in 2015 compared to 2016 was indicated by the unexpected reentry of spiny dogfish in 2015 following their departure in mid-August. Utilizing the polynomial regression model from 2015, spiny dogfish were determined to reenter the Jeffrey's Ledge fishing area on 9/15. No reentry pattern was observed in 2016. It is possible that spiny dogfish possibly reentered Jeffrey's Ledge later in October during 2016, but the act of dogfish 'reentry' into Jeffrey's Ledge fundamentally challenges the annual migration pattern of the species. Further collections of dogfish catch further north (Maine) and further south (Massachusetts) would need to be collected in order to determine if similar reentry patterns are observed for spiny dogfish in the GOM.

It is important to reiterate that this data collection only involves dogfish and water temperature monitoring from two years; thus providing the equivalent of two data points. With further monitoring of dogfish and benthic water temperature, it may become clear that one (or both) of these initial research years is an outlier in terms of a potential "critical" water temperature that triggers dogfish departure. It is important to mention stark differences between the previous years winters prior to data collection (e.g. Jan – April 2015 + 2016). Monthly average temperatures (as recorded at nearby Logan Airport, Boston, MA), were noticeably lower in 2015 (-3.28˚C, -7.2˚C, 0.67˚C, 8.89˚C respectively) compared to 2016 (0.28˚C, 1.5˚C, 5.83˚C, and 8.39˚C respectively; National Weather Service Forecast Office, NOAA). Considering that water temperatures were significantly cooler in 2015, it could be that either year could potentially be an outlier concerning dogfish movements. As was reiterated concerning the TOA, additional data collection of spiny dogfish catch and benthic water temperature recordings needs to be conducted in order to improve our limited understanding of how the two variables are related.

Analysis of the recreational fisherman's landings of spiny dogfish and benthic water temperature data collected during summer 2016 (Phase IIIB) revealed similar trends as found in both Phases II and IIIA in terms of commercial dogfish landings. Unlike the models created using the dogfish landings from the commercial fisherman, the recreational landings indicated a much earlier TOD on 7/16 when water temperatures were approximately 6.00˚C ± 0.04˚C. This timing indicated a TOD that differed from 2015 and 2016 commercial spiny dogfish landings by over 3 weeks in both cases. In addition the time of reentry was calculated for the recreational landings of spiny dogfish landings on 9/15. It is important to note that there was no time of reentry calculated from the commercial landings of spiny dogfish during Phase IIIA.

Interestingly the temperature at TOD for the recreational dogfish landings was very close to that as collected at the TOD in 2015 during Phase II (6.00˚C in 2016 versus 6.16˚C at TOD in 2015). Due to the differences in fishing gear and lack of temperature data and dogfish catch associated with the recreational landings, it is impossible to wholly compare the results between Phases IIIA (Jeffrey's Ledge) and Phase IIIB.

Comparisons were also made concerning the collection of benthic water temperature at Jeffrey's Ledge onboard the commercial fisherman at Jeffrey's Ledge (Phase IIIA) and the recreational fisherman (Phase IIIB). In Phase IIIA on 7/08, benthic water temperature was recorded at 6.03˚C ± 0.03˚C, a difference of approximately 0.04˚C compared to the recordings during Phase IIIB. In August, benthic temperature recordings revealed an average of 7.40˚C ± 0.09˚C on 8/18 onboard the commercial fishing vessel (Phase IIIA), indicating a difference of approximately 0.95˚C compared to Phase IIIB on the same date. Given that the fishermen were fishing the same area (Jeffrey's Ledge) during the same year, it makes logistical sense that the recorded temperature readings were similar. The difference of almost 1˚C as recorded on 8/18 could be attributed to a possible difference in depth along Jeffrey's Ledge that was not accounted for during this study. Further temperature comparisons would need to be made during future collections in order to determine the source of this variation.

Spiny dogfish landings from Phase IIIB could not be compared wholly to the commercial catch of dogfish at Jeffrey's Ledge. This was due to the use of different fishing gear by each fishermen, preventing the calculation of standard CPUE for dogfish. Exact quantities aside, the general pattern of dogfish catch by the charter fishermen followed the same initial increase in catch during mid-summer (July) as noted by the aforementioned Jeffrey's Ledge commercial fisherman. The models from Phase II and Phase IIIB suggest a potential reentry of dogfish into the Jeffrey's Ledge fishing area, an important finding that was markedly absent from data collection from 2016 commercial landings.

The final assessment of this comprehensive study focused on comparing benthic water temperature results between seasons at Jeffrey's Ledge (2015 – 2016) in addition to Platt's Bank (Figure 15). The inclusion of Platt's Bank took place in 2016 and represented a novel approach to compare benthic water temperature in terms of distance from shore (Jeffrey's Ledge (29mi), Platt's Bank (60mi)) despite both fishing areas having similar depth.

Results from this temperature analysis revealed significant differences between all three data sets (Table 1). Water temperatures collected at Jeffrey's Ledge differed significantly between 2015 and 2016. This further supports the need for additional temperature collection and spiny dogfish landings data to further investigate inherent variability in the system.

Temperature analysis from Platt's Bank in 2016 revealed that the benthic water temperature was between Jeffrey's Ledge (2016) and Jeffrey's Ledge (2015). Water temperatures were supported as warming much slower at Platt's Bank, perhaps this being attributed to its further distance offshore. The fisherman who consistently fished at Platt's Bank did not target spiny dogfish at all over the course of 2016. Future data collections associated with Platt's Bank should attempt to quantify and track the spiny dogfish bycatch that was noted by the research technician onboard the fishing vessel.

Future Research:

Although not directly collected over the course of this study, the field technician who collected the dogfish catch data noticed stark differences in the stock structure over the course of the field season in 2016. Across Phases IIIA and IIIB, the technician noted that there was a noticeable shift between spiny dogfish sex ratio from July into mid-August. Early in July to approximately early August, all of the spiny dogfish landed were pregnant females, usually containing 2-3 pups that were often aborted when the dogfish were unloaded at the harbor. It was very uncommon to observe a male dogfish caught during this time period, and the sex ratio of female:male was estimated at 99:1. By mid-August, not too long after the 2016 TOD at Jeffrey's Ledge, it was noted that the sex ratio had become almost even (50:50) and smaller dogfish were caught in higher densities compared to the pregnant females caught earlier in the season.

This novel observation has not been noted in scientific literature to our record. The presence of large aggregations of pregnant females in July-early August suggest that dogfish could potentially be using the Jeffrey's Ledge areas as a pupping ground, perhaps due to its abundant prey availability or preferred water temperature. Due to the emerging importance of spiny dogfish as an economically profitable fishery in the GOM in recent years, any information pertaining to pupping and/or spawning grounds for spiny dogfish is very critical in terms of their proper management. Future collections associated with this study will incorporate data collection to capture changes in sex ratio and gestation stage of the dogfish at each location.

In addition to analysis of stock structure, this project aims to pursue a novel model to compare bycatch of spiny dogfish associated with different size gillnets. Implementation of this model would allow for incorporation of gillnet fishermen who target species such as Monkfish using larger size gillnet mesh. Creation of this model would thus allow inclusion of catch data from the fisherman out at Platt's Bank who solely targets Goosefish. Being able to quantify and compare this bycatch with future dogfish landings at Jeffrey's Ledge could lead to accurate comparisons between dogfish landings at both areas. This in turn could lead to determination of TOA and TOD of dogfish at Platt's Bank and subsequent comparisons to those dates at Jeffrey's Ledge.

Final Thoughts:

In conclusion, this analysis focused on determining the TOA and TOD for Spiny Dogfish at Jeffrey's Ledge in the GOM. The data lacks support for a benthic water temperature correlation, but does suggest a possible temporal relationship associated with dogfish TOD in the fall. This was seen in the similar departure dates in both 2015 and 2016. In addition, initial observations revealed a possible pattern associated with dogfish sex ratios, particularly a shift from pregnant female dominated aggregations in early summer to mixed male:female aggregations approaching early fall. Data collection is planned for 2017 and also expands the working areas of this project to look at popular fishing areas in the Southern GOM off the coast of Massachusetts. This project also seeks to further explore the observations of the field technician (sex ratio and pupping) and also plans to develop methods for comparing the bycatch from the volunteer fishermen at Platt's Ledge to the overall landings for dogfish at Jeffrey's Ledge. Any and all information pertaining to spiny dogfish is critical to further understanding this emerging fishery in the GOM. Understanding this species can hopefully prevent the possibility of future stock crashes for this species in the GOM.

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